Passive Millimeter Wave (PMMW) Imaging Device for Naval Special Warfare

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LONG-TERM GOALS

The long term goal is to demonstrate a prototype, lightweight, low power and low-cost passive millimeter wave (PMMW) imager, which is capable of supporting Naval Special Warfare (NSW). PMMW wave imaging technology will provide NSW the capability to perform operations under severe fog/smoke conditions, and to perform concealed object and through-wall imaging. Clothing, wood, sheetrock and other construction materials are transmissive to the long wavelengths of millimeter wave radiation, allowing for the imaging of objects concealed behind them. A PMMW imaging system will provide day/night all weather vision capabilities under a variety of operations. This supports a Special Operations Command (SOCOM) Technology Development Objective for enhanced vision capabilities and supports the mission areas of combating terrorism and direct action for rescue operations.

OBJECTIVES

The objective of the program's initial phase is to assess the feasibility of a hand held passive millimeter wave imaging device for counter terrorism and adverse weather operational support. The objective of the second phase of the program is to fabricate and demonstrate a prototype antenna coupled microbolometer array for PMMW imaging. An antenna coupled microbolometer array will provide a lightweight, low power, and low cost PMMW imaging sensor. The initial device will be a prototype device and will be integrated into an existing testbed (lens and data acquisition).

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APPROACH

The PMMW task consists of two efforts that were executed simultaneously during FY 98. The first effort was conducted jointly by Nichols Research Corporation (NRC) and Coastal Systems Station (CSS) while the second effort was conducted by Intelligent Machine Technology (IMT). The first effort was a feasibility assessment of PMMW sensors to determine whether they meet NSW mission requirements. The assessment included a requirements analysis, a technology survey, a performance analysis, and a technology recommendation. This led to the identification of the antenna-coupled microbolometer array technology as a high-risk, high-payoff approach to PMMW imaging. The second effort is being conducted by IMT because of their past experience in the sensor arena related to the development of microbolometers. IMT is developing a low noise antenna-coupled microbolometer 2D sensor array that will be batch processed so the cost can be held to a minimum. The sensor has the potential to be tuned to literally any wavelength, and multi-spectral operation is an option.

WORK COMPLETED

Feasibility Assessment

Over the last fiscal year, several major events took place. The first was a data collection activity, which was conducted jointly with AFRL/MNGI. The data collection took place at Eglin AFB and at CSS. The data collection activities covered a time period of nearly six months, however data was not collected continuously over that time period. Data were collected for maritime targets, through smoke and through various thicknesses of selected materials. The analysis of the data is an ongoing process. Modeling of through material performance was performed and validated with test data. Data collection results were presented at International Symposiums, SPIE AeroSense in Orlando, FL and Progress in Electromagnetics Research Symposium 98 (PIERS 98), in Nantes, France.

Coordination has begun with the United Kingdom's Defense Evaluation and Research Agency (DERA) for an International PMMW Imaging Demonstration. This will be a data, modeling, and hardware exchange program aimed at furthering PMMW imaging technology for Defense related applications.

Antenna-Coupled Microbolometer Development

In order for PMMW to be viable for NSW applications, the technology must be made smaller, cheaper, and data collection more rapid. Antenna-Coupled Microbolometer technology has the potential to do this. The concept requires efficient energy collection by the antenna and coupling to the bolometer, high thermal isolation of the bolometer for sensitive response, and minimum noise from the system. The following efforts have been performed to determine the feasibility of the concept:

<u>Design for Low Thermal Conductance between Bolometer and Ground</u>. The selected design is a composite, using different materials for the antenna load and the active bolometer.
<u>Feasibility of Achieving "Phonon Limited" Noise Level</u>. The thermal bridge that forms the antenna load and carries the sensitive bolometer material is a very important part of the structure. The thermal bridge has been designed, and test articles derived from that design are being fabricated. The biasing and signal extraction circuitry has been determined, and such circuitry is being prepared for the test articles. Four test articles are in fabrication.

Determine Low 1/f (Flicker) Noise with the Bolometer Material Chosen. Bismuth, and titanium have been grown and material property measurements taken.
Determine an Efficient Antenna-Coupled Design. Using Ansoft's Maxwell High Frequency Structures Simulator (HFFS v.5) at Lockheed Martin Vought Systems, a simple half-wave dipole and a bow tie dipole have been modeled with regard to coupling efficiency and bandwidth.
Determine a Polarization-Independent Design. A method was developed for acquiring both polarization components of the incoming radiation.
Show Electrical Isolation between Signal Extraction and Antenna Efficiency. It was discovered that the problem of isolating the low frequency signal leads from the high frequency radiation paths in the antenna structure may be simply solved. The metallic antenna structure sits 1/4 wavelength above the ground plane. By bringing the signal leads straight down from the antenna to the plane, they form a 1/4 wave short, which makes them appear as open circuits at the bolometer load.
Show Feasibility of Fabrication of Desired Structure. The fabrication of the thermal bridge is underway and will be tested in November 99.

RESULTS

Feasibility Assessment

Several tests were performed at CSS in a maritime environment. The main purposes of these tests were to study the phenomenology of maritime PMMW signatures and to evaluate the feasibility of a PMMW boat navigation device. Figure 1 contains images of a Coast Guard Cutter located 300 feet across a bayou. In the PMMW image, white is hot and black is cold. The boat is constructed of metal; therefore, it is highly reflective in the PMMW imagery. The front surface of the boat is tapered and reflects the waters energy into the radiometer. The super structure in the front has surfaces, which are reflecting the cold sky into the radiometer. The shoreline is obvious, as the soil, grass and trees are highly emissive and therefore, warmer than the water which is only about 50% emissive. Figure 2 illustrates the contrast between personnel swimming in the water and the water in the presence of a solar specular reflection. The persons are highly emissive, while the water is again only about 50% emissive. The solar reflections are not seen in the MMW regime. This is due to the fact that the solar disk is tightly constrained, because the atmosphere does not scatter the solar energy as it does in the visible. The PMMW signatures of the swimmers are unaffected by them being wet. One swimmer has on a mask, which also has no effect on the signature. The neoprene wetsuits are highly transmissive in the MMW regime and therefore, do not affect the PMMW signature either. Many other images were taken, but space limitations of this report preclude showing them all here.

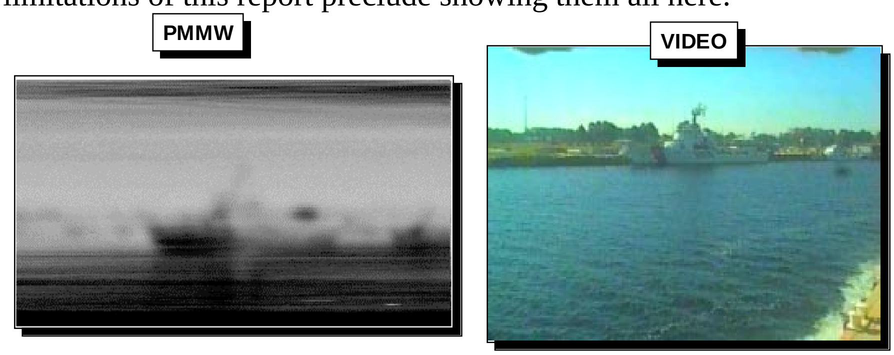


Figure 1. 95 GHz PMMW Imagery of Coast Guard Cutter against Shoreline.

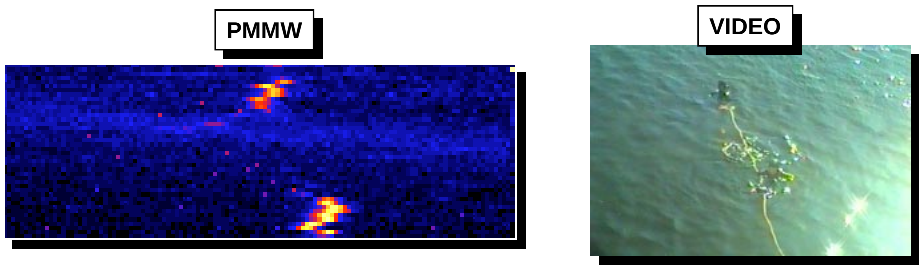


Figure 2. 95 GHz PMMW Imagery of Swimmers in the Water.

Antenna-Coupled Microbolometer Development

Bismuth has been grown and partially characterized. 1/f noise measurements have been made on titanium and bismuth. The data are shown in Figure 3. Results with titanium are particularly encouraging in that the 1/f knee frequency is around 5 Hz, close to the goal of 1-2 Hz.

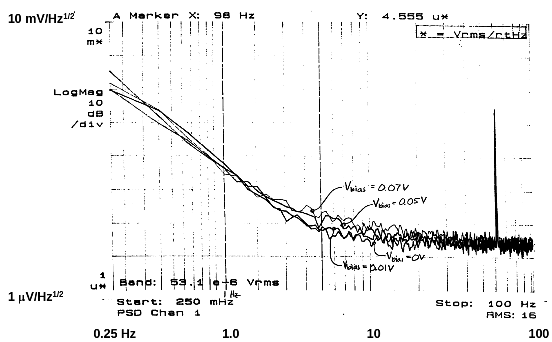


Figure 3a. Noise Measurements on 0.01 μm Titanium Film on Si_3N_4.

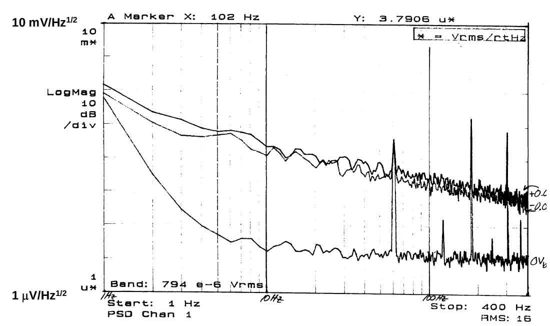
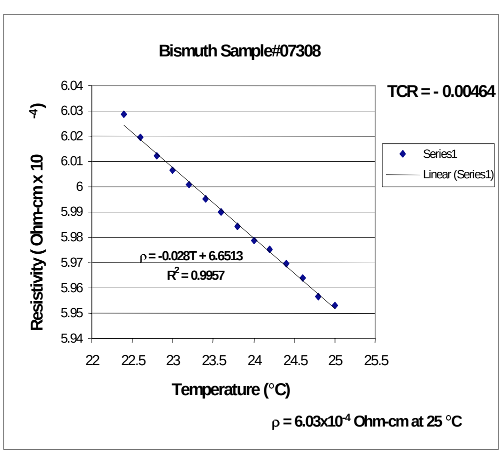


Figure 3b. Noise Measurements on 0.3 μm Bismuth Film on Si_3N_4.

The results are also independent of bias current, meaning that the noise most likely originates in the contacts. The contacts are more readily improved than the material. The deposited bismuth shows some instability. The 1/f knee frequency here is of secondary interest, but stability is important. This latter remains to be worked. Resistivity and thermal coefficient of resistance (TCR) have been measured for bismuth. The results are shown in figure 4.



Resistivity of the bismuth film is 6.03 $\times 10^{-4}$ Ohm-cm at 22.5 °C, about twice the resistivity of the typical electron-beam deposited film. The temperature coefficient of resistance (TCR) was measured to be -0.00464 °C^{-1} at room temperature, about 30% higher than the measured TCR for the typical electron-beam deposited bismuth film.

Modeling of a bow tie antenna and a conventional dipole antenna on an infinite dielectric slab with ground plane has been accomplished. Radiation efficiency exceeds 90% over a

spectral band from 80 GHz to beyond 120 GHz for the Figure 4. Resistivity vs. Temperature for a bow tie antenna. However, this merely shows that high Resistively Deposited Bismuth Film broadband efficiency can be achieved. Additional modeling is necessary to match the antenna to the receiving optics.

Summary: Task I is close to completion. All seven issues described above have been addressed. The most important activity has been the development of the thermal bridge that contains the bolometer and the biasing and signal extraction circuit. Both are unique, and are uniquely matched to the bolometer material. This combination offers the capability of achieving the lowest noise level theoretically possible for a given operating temperature.

TRANSITIONS

The most likely transition for this technology is through either Explosive Ordnance/Low Intensity Conflict (EOD/LIC) or Special Operations Special Technologies (SOST) programs funded through United States Special Operations Command (SOCOM).

RELATED PROJECTS

Eglin AFB Wright Laboratory, Munition Processing Technology Branch - Smart Tactical Autonomous Guidance program. This is an umbrella program that seeks to develop PMMW imaging radiometers and 3-dimensional imaging algorithms for cruise missile mid course guidance. Several SBIRs are underway including the following development efforts:

- “Image Flow Algorithms” for passive 3-dimensional imaging.
- Focal plane scanned imaging radiometer based on MMIC low noise amplifier direct detection.
- Radiometer with >0.01 K sensitivities for performing phenomenology investigations.
- Several other novel PMMW imaging concepts.

National Institute of Justice/Defense Advanced Research Projects Agency (DARPA) Operations Other Than War (OOTW). Dual mode infrared/millimeter wave camera development for conceal weapon detection.

DARPA Technology Reinvestment Program. PMMW camera development for aircraft landing systems.

Marine Corps Technology Program. Technology assessment of PMMW sensor for standoff airborne mine detection.

Office of Naval Research - PMMW Technology Leveraging Program. Leveraging of DARPA TRP PMMW camera development and DARPA MMIC program to demonstrate PMMW imaging capabilities for Marine Corps applications.

PUBLICATIONS

Blume, B., 1998: “Passive Millimeter Wave Technology,” Short Course Instructor, SPIE AeroSense.

Blume, B., Wood, J., and Downs, F., 1998: "Naval Special Warfare PMMW Data Collection Results," *Proceedings of Passive Millimeter Wave Imaging Technology II*, SPIE Vol. 3378, April.

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